Computers & Operations Research 66 (2016) 393–401

Contents lists available at ScienceDirect

Computers & Operations Research

journal homepage: www.elsevier.com/locate/caor

An artificial neural network based decision support system for energy efficient ship operations

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ARTICLE INFO

Available online 24 April 2015

Keywords:
Ship energy efficiency
Operational measures
Decision support system
Artificial neural networks

ABSTRACT

Reducing fuel consumption of ships against volatile fuel prices and greenhouse gas emissions resulted from international shipping are the challenges that the industry faces today. The potential for fuel savings is possible for new builds, as well as for existing ships through increased energy efficiency measures; technical and operational respectively. The limitations of implementing technical measures increase the potential of operational measures for energy efficient ship operations. Ship owners and operators need to rationalise their energy use and produce energy efficient solutions. Reducing the speed of the ship is the most efficient method in terms of fuel economy and environmental impact. The aim of this paper is twofold: (i) predict ship fuel consumption for various operational conditions through an inexact method, Artificial Neural Network ANN; (ii) develop a decision support system (DSS) employing ANN-based fuel prediction model to be used on-board ships on a real time basis for energy efficient ship operations. The fuel prediction model uses operating data – 'Noon Data' – which provides information on a ship's daily fuel consumption. The parameters considered for fuel prediction are ship speed, revolutions per minute (RPM), mean draft, trim, cargo quantity on board, wind and sea effects, in which output data of ANN is fuel consumption. The performance of the ANN is compared with multiple regression analysis (MR), a widely used surface fitting method, and its superiority is confirmed. The developed DSS is exemplified with two scenarios, and it can be concluded that it has a promising potential to provide strategic approach when ship operators have to make their decisions at an operational level considering both the economic and environmental aspects.

1. Introduction

1.1. Ship energy efficiency measures and the importance of developing a decision support system

CO_2 emissions generated by maritime transport represent a significant part of total global greenhouse gas (GHG) emissions. According to the International Maritime Organisation (IMO), ships emitted 1016 million tonnes of CO_2 on average for the period 2007–2012 which make up approximately 3.1% of global emissions [1].

With the tripling of world trade, if no action is taken, it is assumed that the emissions from shipping will increase by 50%–250% until 2050 [1]. OECD also reported a similar level of prediction in the increase in CO_2 emissions from shipping [2].

As there is a strong demand for ships to reduce the emissions, a number of current research activities focus on estimating global shipping emissions and develop mitigating solutions to tackle the problem, e.g. [3–10]. In addition, the rising and volatile fuel prices constitutes a major problem for shipping companies as the fuel cost forms 60% of the ship operating cost [11]. As a result, shipping companies are moving towards energy efficient procedures and operations for reducing energy consumption in order to lower their management costs and thereby maintain their competitive position in the market and to reduce negative environmental impacts.

Ship energy efficiency measures offer various options to ship owners and operators to reduce fuel consumption and emissions. In 2011, IMO's Marine Environment Protection Committee (MEPC) adopted the amendments to International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, as a new chapter (Chapter 4). Through this, Energy Efficiency Design Index (EEDI) for new ships and Ship Energy Efficiency Management Plan (SEEMP) for all ships have been made compulsory from 1 January 2013 [12]. While EEDI facilitates implementation of technical

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http://dx.doi.org/10.1016/j.cor.2015.04.004
0305-0548/

measures through design to meet the carbon emission limits for new ships, SEEMP aims to increase the energy efficiency, through operational applications that are developed using the existing technologies in ships, including crew awareness and training on energy efficiency. For the above reasons, the fuel saving of ships has become paramount for ship energy efficiency.

1.2. Overview and requirements for ship operational energy efficiency decision support system

Decision support systems (DSS) are kinds of computer-based information system that can help decision makers utilize data, models and other knowledge on the computer to solve semi structural and some non-structural problems, which cannot be measured or modelled. This aspect of semi-structured problems requires human intervention, and therefore, solutions to semi-structured problems are often achieved by allowing a decision-maker to select and evaluate practical solutions from a finite set of alternatives. The aim of DSS is to help decision makers improve decision-making effectiveness and efficiency by combining information resources and analysis tools [13].

Combined effects of several factors are involved for evaluating ship operational energy efficiency measures. Determining a strategic implementation becomes more complicated for ship operators due to its complexity and difficulty. There is a need for decision support to provide quickly and directly solution for predicting fuel consumption at an operational level through implementing operational measures using the existing technologies in ships to increase energy efficiency and to decrease environmental effects and overall costs.

'Noon Data' reports provide valuable information on the fuel consumption of ships under various loading, speed and weather conditions that can be utilised for development of the ship operational energy efficiency Noon reports, unfortunately, have not been utilised fully by the shipping companies towards energy efficient operations, as in most cases they were collected in order to comply with regulations. Therefore, the potential benefits of noon reports towards developing an energy efficiency strategy has not been realised by many companies. Noon data, unless collected and analysed in a systematic way, will be less beneficial. Furthermore, a proper study of Noon data with a focus on energy efficiency, can only be performed by accessing other ship/operation related information (quantity of cargo, draft marks, shaft power etc.) which are not provided in the noon reports. This paper aims to address the gap by developing an innovative approach for shipping companies to utilise the noon data for improving the energy efficiency.

1.3. The use of artificial neural networks and related literature

One of the methods used as an alternative to traditional estimation methods is artificial neural network for complex systems [14]. As long as there are adequate samples, the input variables accurately state the output variable through the "training" process of ANN. Considering the nature of data, appropriate methods should be selected to obtain best-fit prediction. This study finds that Artificial neural network (ANN) technology is suited for on-site optimization of ship operational measures related energy efficiency.

In quest of emulating the working principles of human brain, ANN is a field of computational science developed over the recent years to deal with the complex systems, which are very difficult or even impossible to model using other analytical and statistical methods. ANN is well suited for prediction purpose as it can approximate successfully any measurable function [15]. The forecasting capabilities of ANN were acknowledged in the past [14]. ANN shows great adaptability, robustness and fault tolerance due to the large number of highly interconnected processing elements [16]. The surface fitting capabilities of ANNs will be essential for our case and this is the reason why ANN was selected to be used for our study [17].

Numerous studies in different disciplines have been undertaken to predict the fuel consumption by using ANN models [18,19,20,21]. ANN has been found to be the domain for many successful applications of prediction tasks, in modelling and prediction of energy-engineering systems [22], prediction of the energy consumption of passive solar buildings [23], developing energy system and forecast of energy consumption [24], and analysis of reduction of emissions [25]. There are also some relevant reports of ANN's use based on decision support systems in various subjects such as solving the buffer allocation problem in reliable production [26], developing environmental emergency decision support systems [27], risk assessment on prediction of terrorism insurgency [28] and metamodeling of simulation metamodel [29]. ANN has been used to predict specific fuel consumption and exhaust temperature of a Diesel engine for various injection timings [30]. However, no paper is found that modelled fuel consumption using ANN for decision support system based on ship operating data -'Noon Data'.

1.4. Aim of this study

The study on operations research (OR) in energy modelling and management based maritime transportation had great attention in recent decades. Ronen [31] examined the tradeoff between fuel savings through speed reduction and the loss of incomes as a result of voyage extension. Brown et al. [32] focused a scheduling problem for crude oil tanker and determined optimal speeds for the ships, the best routing of ballast legs and cargo assignment. Perakis and Papadakis [33,34] decided the fleet deployment and the related optimal speed for ships between one loading port and one unloading port. They later improved their research with multiple loading ports and multiple unloading ports [35]. Yao et al. [36] examined the relationship between bunker fuel consumption rate and ship speed for different sizes of container-ships based on real data obtained from a shipping company.

The majority of these studies focused on speed optimization. To the best of authors' knowledge, there is no study that takes into account ship's operating data including speed, trim and weather effects along with decision making in order to minimize ship fuel consumption.

The aim of this paper is twofold: (i) predict ship fuel consumption for various operational conditions through ANN; (ii) develop a decision support system employing ANN based fuel prediction model to be used on-board ships on a real time basis for energy efficient ship operations. The goal of the ANN is to predict ship fuel consumption under various operational conditions using operating data – 'Noon Data' – which provides information on a ship's daily fuel consumption.

The rest of this paper is organized as follows. In Section 2, the methods and data conducted in this study is presented. Sections 3 and 4 describe the design and development of the ship operational energy efficiency ANN system that predicts ship fuel consumption under various operational conditions, based on the noon data. In Section 5, the performance of the developed Artificial Neural Network (ANN) is compared with multiple regression analysis (MR), another well-known surface fitting method. Section 6 discusses the design of the (DSS) for improving ship energy. The last section draw conclusions and recommendations for further research.

2. Methods and data

2.1. Modelling of ship fuel consumption

Ship fuel consumption and its prediction is modelled in three parts: a database of ship fuel consumption obtained from the